



Scaling and suppression of motional decoherence in an adjustable ion trap

W. K. Hensinger^{1,2}, L. Deslauriers¹, S. Olmschenk¹, D. Stick¹, J. Sterk¹, and C. Monroe¹

¹ FOCUS Center and Department of Physics, University of Michigan, Ann Arbor, MI 48109

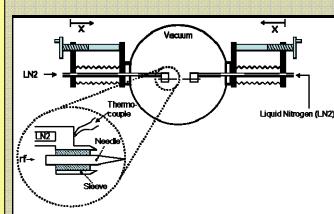
²Department of Physics and Astronomy, University of Sussex, Falmer, Brighton, East Sussex, BN1 9QH, UK



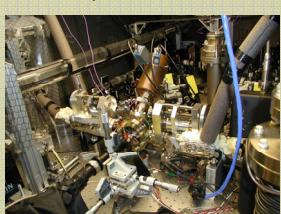
An ion trap with adjustable electrodes



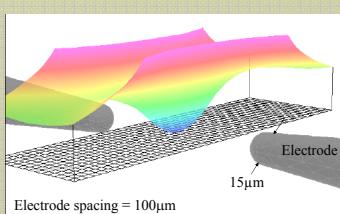
Trap Schematic



Vacuum system



Potential

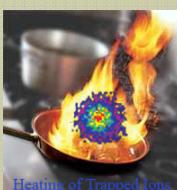


Investigating anomalous motional decoherence

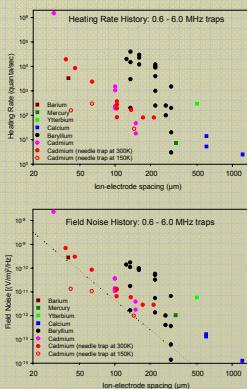
Heating of the motional states of trapped ions may be a source of decoherence for many quantum logic gate schemes [1]. We measure and characterize the anomalous motional decoherence of a $^{113}\text{Cd}^+$ ion confined in a novel rf quadrupole trap which features moveable electrodes.

- Motional heating as a function of electrode spacing ($2z_0$)
- Motional heating at low temperature (~150K)
- Motional heating as a function of secular frequency

$$S_E(\omega_z) = \int d\tau \langle E(t+\tau)E(t) \rangle e^{i\omega_z t}$$



Previous heating history in ion traps



Using data from previous experiments it is difficult to study this anomalous heating in a controlled way, because of comparisons across different trap structures, materials, surface qualities, and ion species.

General Heating and Thermal Noise

The heating rate of the secular motion is related to the power spectrum of the electric field noise by [iii]:

$$\dot{n} = \frac{e^2}{4m\hbar\omega_z} \left(S_E(\omega_z) + \frac{\omega_z^2}{2\Omega^2} S_E(\Omega \pm \omega_z) \right)$$

The thermal (Johnson) noise from the resistive elements (shown on the left) is estimated to be:

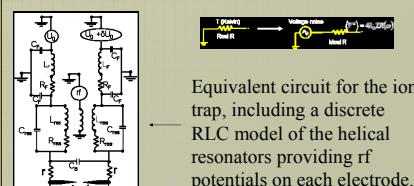
$$[S_E(\omega)]_{thermal} = \frac{8k_B T R(\omega)}{(1 + R(\omega)^2 C^2 \omega^2)} + 8k_B T' r(\omega)$$

Ultimately, at 300K we expect the heating rate due to thermal noise to be:

$$\dot{n} \sim \left(\frac{200}{z_0} \right)^2 \left(\frac{2\pi}{\omega_z} \right)$$

At 150K, this would be reduced by a factor of ~6, as a result of the reduction of the resistivity of the tungsten electrodes.

Johnson noise



Equivalent circuit for the ion trap, including a discrete RLC model of the helical resonators providing rf potentials on each electrode.

The thermal noise at the rf sideband frequencies $\pm\omega_z$ is dominated by the large effective resistance of the resonator circuit $R(\Omega \pm \omega_z) \approx (\Omega / 2\omega_z)^2 R_{res}$, where $R_{res} \sim 0.1$ is the dc series resistance of the resonator. But this near-resonant enhancement is offset by the $(\omega_z / \Omega)^2$ term, therefore this source of thermal noise can be neglected compared to noise at ω_z .

Anomalous “patch” potential heating

Heating data from previous experiments [iii],[iv] indicates that the magnitude of observed heating is significantly larger than expected from thermal (Johnson) noise and is thought to originate from microscopic “patch” potentials [iv].



- [i] D. J. Wineland, et al., NIST J. Res. **103**, 259 (1998)
- [ii] Q. A. Turchette, et al., Phys. Rev. A **61**, 063418 (2000)
- [iii] L. Deslauriers, et al., Phys. Rev. A **70**, 043408 (2004)
- [iv] J. B. Camp, T. W. Darling, and R. E. Brown, J. Appl. Phys. **69**, 7126 (1991)

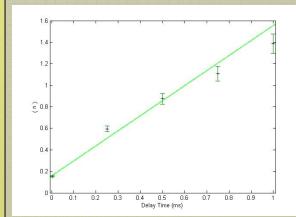
Sideband Thermometry

The average occupational number (\bar{n}) determines the “temperature” of the trapped ion. Experimentally, the value of \bar{n} is obtained by measuring the asymmetry between the first-order red and blue sidebands. Then, for a thermal state of motion [2],

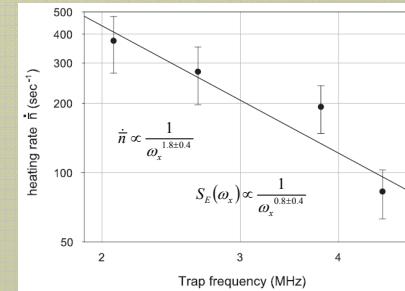
$$\bar{n} = \frac{R}{1-R}$$

Here $R = I_{bs}/I_{rs}$ where I_{bs} and I_{rs} are the amplitudes of the blue and red sidebands, respectively. By inserting various delay times between cooling and measuring the ion, we are able to extract the heating rate \dot{n}

Measuring Heating: \bar{n} vs. Delay Time



Frequency spectrum of heating



Power spectrum scales as expected as $1/f$

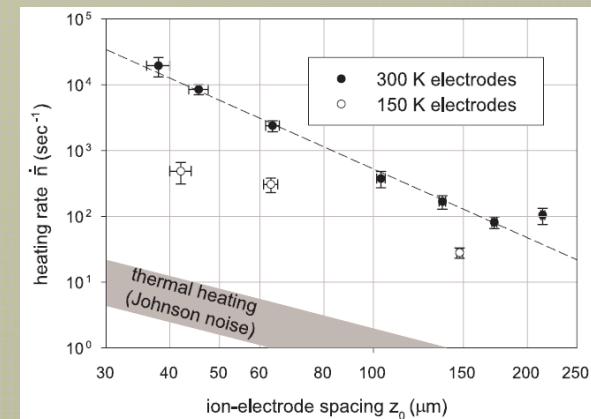
Heating versus Trap Size

At ~300 K, the motional heating of a single trapped ion was measured as a function of z_0 (distance to the nearest electrode).

$$\dot{n} \propto \frac{1}{z_0^{3.5}}$$

During this process, $\omega_z/2\pi$ was kept at 2.07 MHz.

Measurements were repeated while cooling the vacuum chamber with liquid nitrogen (final temperature at the tip of the needle calculated to be ~150 K). The heating rate dropped by a factor of ~10. This result confirms the source of the electric field noise is the trap electrodes.



Reducing the temperature of the electrodes by a factor of ~2 suppresses the heating by a factor of ~10. This suggests that the anomalous heating observed in ion traps may be thermally driven and activated at a threshold temperature, and that further cooling to 77 K or lower may even quench this anomalous heating completely.